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ABSTRACT

Reviewed are several pertinent research articles dealing with cognitive development, Piaget's theories, and science instruction, especially those that relate to procedures that can be implemented by classroom teachers. The research findings on developmental levels of Piaget discuss: (1) tasks that indicate a change from preoperational to concrete operational abilities and from concrete to formal operations; (2) science concepts and developmental levels; and (3) teaching and development. An outline of Piaget's stages of intellectual development is also included. (HM)

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COGNITIVE DEVELOPMENT AND SCIENCE INSTRUCTION: A REVIEW OF SOME RECENT RESEARCH FINDINGS

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COGNITIVE DEVELOPMENT AND SCIENCE INSTRUCTION: A REVIEW OF SOME RECENT RESEARCH FINDINGS

Michael Padilla

> If Piaget's notions are correct, then much of the time spent on science instruction in elementary and middle schools today is wasted. Even worse, if we continue to insist that students learn ideas that they are unable to understand because they lack the logical structures necessary for understanding, they have little choice but to resort to rote memory. As a result, they develop poor study habits, poor attitudes toward school and low self image. (Herron, p. 602, 1978)

Many recent professional and research articles have focused on the relationship between cognitive development and science education. Great emphasis has been placed on stages of development, Piaget's writings, testing and training procedures, and the goals of science education. So much has been written on this topic that an intellectual mystique has begun to cloud important findings, especially for the classroom teacher. It is the intent of this paper to try to demystify this topic by reviewing several pertinent research articles dealing with cognitive development and science instruction, especially those that relate to procedures that can be implemented by classroom teachers.

Developmental Stages Reviewed

Piaget (1963) and his co-workers defined four basic, sequential stages of development which are outlined in Figure 1. Of greatest interest to educators are late preoperational through formal operational stages since these span the ages of most school children.

Generally speaking, children in late preoperations have a highly self-centered view of the world in which they are only able to interpret phenomena by dealing with one variable at a time. Over time, the child's world view changes to include other points of view and to deal with more than one variable at a time <u>if</u> presented with concrete situations and materials (concrete operations). Ultimately, he may begin to use such sophisticated thought processes as proportional

reasoning, identifying and controlling variables, formulating and testing hypotheses and generating multiple combinations (formal operations). The reader who is unfamiliar with these stages, should take a moment to read through and analyze the statements in Figure 1, since the stages and developmental characteristics will be referred to throughout the following paragraphs.

One further note should be emphasized. Piaget wished to make generalizations about the "cognitive structures" that a child had available for solving logical thought problems. It is obvious that one cannot simply measure these structures, but rather must infer their existence through physical and verbal responses to problem situations. These responses are the heart of Piaget's clinical method in which the child is asked to manipulate physical materials in response to a problem statement and then to justify his solution orally. Thus in the following discussion, reference will be made to students' abilities with tasks, but the reader must be aware that it is the cognitive structures that allow the student to be successful with any task.

Research Findings on Developmental Levels

Piaget defined general age levels for each stage stating that these were average ages at which children achieved the operations involved. He strongly stressed that individuals vary greatly in onset age of any stage but that each individual would go through the same invariant sequence of development. While the onset age of a stage was of minor importance to Piaget, it is a major concern in education, since educators would like to generalize about appropriate teaching methods and materials.

The Change from Preoperations to Concrete Operations

The most commonly researched tasks that indicate a change from preoperational to concrete operational abilities include seriation, classification and

conservation tasks. Seriation implies an understanding of order. Thus a successful seriator will be able to put a set of 10 sticks in order from tallest to shortest and to insert several additional sticks appropriately into the ordered row. Classification implies an understanding of class relationships. Thus one classification task asks the child to sort a set of objects based on one attribute and then to resort those objects, giving an adequate explanation for the sorting in each case. Conservation tasks involve the notion of what stays the same in a system when certain changes take place. Thus a successful conserver states that the amount of water in a container does not change when it is poured from a tall, thin container to a short wide one.

In general, Piaget's statements concerning the end of pre-operational and the beginning of concrete operational stages (about age 5-8) were upheld. Elkind (1964) and Smith and Padilla (1977) found seriation abilities operational in most children by ages 6-8. Kofsky (1966) found all but the very difficult classification tasks mastered by most children age 8. Renner, et al, (1971) showed that most children age 7-8 begin to master the simpler conservation tasks like number, solid amount, and liquid amount. Implications that can be drawn for teaching will be discussed in a later section but the early elementary classroom teacher wishing to use some of the above tasks with his/her students can refer to Renner, et al, (1971) for directions on several conservation tasks.

The Change from Concrete to Formal Operations

While there is some disagreement as to what actually constitutes formal thought processes (Lawson, et al, 1978), several standard tasks developed by Piaget have been used extensively. These tasks are problem oriented and usually challenge a subject's ability to identify and control variables, to use proportional thought and/or to use combinatorial reasoning abilities. While there are too many distinct tasks to discuss here, a description of one might be appropriate. For others see Piaget (1958).

In the pendulum experiment the student is confronted with a pendulum and is asked to find out which (if any) variables might affect the frequency of the swing of the pendulum. Four possible variables pointed out to the subject are the length of the string pendulum, the amount of weight at the end of the string, the position from which the pendulum is let go and the force of the push given to the pendulum. To a novice all four variables might seem to logically make a difference. However, after conducting a fair experiment for each of the factors the formal student is able to conclude that only the length of the string makes a difference. Thus this task tests a subject's abilities to identify and control variables and to appropriately generalize from the data gathered. Concrete subjects will not be able to set up a fair and accurate test or will manipulate the data in order to prove what they falsely hypothesized.

Research on the average acquisition age of formal operational thought has not been so easily replicated. Commencing with Lovell in 1962, evidence began accumulating that not all children moved from concrete to formal operations at age 11 or 12. In fact, a great discrepancy between research findings and theory has become evident such that even many college freshman have been found predominantly using concrete thought processes. Chiapetta (1976) states in his summary of several formal operational studies that most (over 85%) adolescents and young adults have not fully developed formal operational abilities. Renner, et al, (1978) tested almost 600 students from grades 7-12 administering 6 tasks to each student. The results (Table 1) show a substantial number not yet able to use abstract thought processes. While other research studies (Kolodiy, 1977; Karplus, et al, 1977) show slightly higher numbers of subjects at formal operational levels, the overall generalization to be drawn is that most children in upper elementary grades, middle and junior high schools and even high schools do not use abstract reasoning. Piaget (1972), himself, has

reassessed his original sample, hypothesizing that they were a privileged group and thus showed accelerated abilities.

Insert Table 1 About Here

Science Concepts and Developmental Levels

The types of concepts preoperational students can master are necessarily limited by their thinking abilities. Activities stressing observation, classification and seriation are necessary to help young children move from the egocentric narrow thought of the preoperational stage. While the research is mixed as to whether specific, short term training can advance children to a new stage, one clear generalization seems true. Children who are developmentally ready to make a change, do so easily and much more quickly when given appropriate practice on the above tasks. It appears that, for the child who is ready, his actions with the materials causes a state of disequilibrium with which he can now deal. He thus assimilates the new actions and accomodates his structures to deal with the new data. In other words, he creates new and much more powerful structures to deal with the world.

Research into concepts that concrete and formal thinkers can master has led to much more startling results. Lawson and Renner (1975) divided biology, physics and chemistry content into either concrete (concepts that "can be developed with first hand experience with objects") or formal (concepts whose meaning is derived through the theoretical models of science, not from concrete objects). Digestion, mixture and bulb brightness are examples of concrete concepts; ecosystem, the mo[illegible] and nuclear energy are formal concepts. After the regular classroom teacher taught a unit, the students were tested for understanding of the material. For the purposes of this study understanding was defined as the ability to answer content questions at comprehension and application levels (Bloom, et al, 1956).

Across all three subject areas, formal students performed considerably higher than concrete students. Especially interesting, however, is the fact that almost no concrete students showed mastery of formal concepts. While formal students did master some formal concepts, they performed much higher on the concrete concepts.

This data as well as that from similar studies (Cantu and Herron, 1978; Goodstein and Howe, 1978) implies that science teachers should be taking a long, hard look at their course content. If a great number of our students are not formal operational, even by grade 12, and if concrete operational students do not learn formal concepts, then this leaves us with two alternatives. We can either concentrate on concrete concepts at the expense of the more abstract ideas of science or we can attempt to develop new teaching procedures that use concrete examples, models and other materials as much as possible in the hopes that a more concrete approach will prove successful. While the data on the latter possibility is not yet complete, it appears that the method which tries to make formal concepts more palatable for concrete students, in fact, helps only formal students (Cantu and Herron, 1978; Goodstein and Howe, 1978). Thus we should, as Goodstein and Howe state, either postpone abstract topics until students are ready or reduce their complexity and abstractness so they can be understood by concrete students.

Teaching and Development

Should teachers only reduce the complexity of science content and not attempt to concomitantly raise the level of thought among students? Hopefully not. We must redouble efforts to identify successful teaching strategies and to apply them in the classroom. While the research on teaching strategies is mixed, it appears that certain kinds of variables hold good hope.

In an excellent review of recent literature Levine and Linn (1977) list several variables relevant to scientific or formal reasoning. Among these are

the number of variables in a given problem, the students' familiarity with the variables, the amount and quality of school experience, the strategy for task completion and the students' problem organization skills. All of the above factors can be controlled by the classroom teacher. By organizing numerous experiences with experimental variables and situations with which children are familiar and by carefully controlling the number and complexity of the variables being considered, the teacher can begin to shape the experiential background of students. It also appears advantageous to present useful learning strategies when appropriate, both ones which help to solve types of problems (e.g., on emphasis on a "fair" experiment) and ones which help to organize and clarify information (use of written records and charts).

Levine and Linn gleaned these generalizations from numerous individual and independent studies. None of these was greatly successful at improving the level of thought as measured by transfer of abilities on highly related tasks. But most used only short term training (from 4 short to 12-40 minute sessions). While long term effects of such procedures can only be conjecture at this time, it does offer good possibilities. As best as can be expected it is these procedures which Karplus, et al, (1977) refer to when they state

> ...teaching can have some influence on the development of reasoning by the students in the age range being tested here (13-15 year olds). Applying proportional or control of variables reasoning is not the result of a process inclusively internal to the young people. (p. 416)

One final note of importance to science teachers should be made. Over the past 20 years or so much emphasis has been placed on science process skills. This new dimension arose out of the curriculum development projects of the 50's and 60's. Of great interest is the similarity between the process skills and many of Piaget's logical abilities. A few good examples are identifying and controlling variables, hypothesizing, application of proportional reasoning in

data interpretation activities, classification, describing relationships and many others. Thus when considering development and science teaching, no new philosophy need be adopted. The classroom teacher must simply continue to use concrete activities stressing appropriate process skills. The only new awareness is that many of the process skill abilities are developmental in nature and thus will not and usually cannot be learned over a short period of time.

Stage	Approximate Age (Years)	Developmental Characteristics
Sensory Motor	0-2	-Sucking and grasping are methods for interacting with and learning about the environment. -Language begins to form -The present is the only time and the immediate the only space
Preopera-tional	2 to 6-7	-Egocentric behavior is prevalent -Objects and feelings are represented by words and symbols -Judgements made in terms of how something looks, usually using only one variable at a time -Actions and operations are not mentally reversible
Concrete Operation	6-7 to 11-12 or even older	-Logical problems can be understood and solved through manipulation of concrete objects or experience only -Can mentally reverse actions and operations -Can classify and order objects -Objects do not change in volume, weight or number wnen they are spatially rearranged (conservation)
Formal Operations	11 or 12 to adult or more recently 15 or 16 to adult	-Can interact in the hypothetical -Can formulate and test hypotheses by identifying and controlling variables -Can generate multiple possibilities -Can reflect on his/her own thought processes -Can solve problems using proportional thought

Figure 1. Outline of Piaget's Stage of Intellectual Development.

Table 1

Incidences of Concrete and Formal Thought
Found in Oklahoma Secondary School Students*

Grade	Sample Size	Percentages of Students Exhibiting	
		Concrete Thought	Formal Thought
7	96	83	17
8	108	77	23
9	94	82	18
10	94	73	27
11	99	71	29
12	97	66	34
TOTAL	588	452 (75%)	148 (25%)

*From Renner, Grant and Sutherland, 1978.
NOTE: Columns did not add up in original table.

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